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A sea-loads-based ship structural design technology includes components related to nonlinear hydrodynamics, nonlinear dynamics, and a probabilistic or reliability-based analysis of ship hydrodynamic loading. The thrust of the research conducted at the University of Michigan was on the prediction of local loads resulting from bottom impact and flare slamming. Details of spray jet development and flow separation points have been investigated and their influence on the overall hydrodynamic loads determined.

The project's goal has been the development of a fundamentally sound methodology by which the design hydrodynamic loads acting on a vessel in extreme seas can be computed. The emphasis was on the prediction of local loads resulting from bottom impact and flare slamming for symmetric and asymmetric hull shapes. The result of the analysis is time histories of pressures and local loads which can now be incorporated into subsequent ship structural analysis.

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FINAL REPORT

Title: *Prediction of Impact Loads Due to Extreme Vessel Motions*

Contract No. N00014-96-1-0482

Principal Investigator: Prof. Armin W. Troesch

ONR Program Manager: Dr. Edwin Rood

Project Period: 1 March 1996 - 31 August 1997

This is primarily an administrative report listing the project goals and major accomplishments. The technical results of the project are described in the various publications listed below in the Publications section. Copies of the most recently submitted publications are included as attachments.

Description of the Scientific Research Goals

A sea-loads-based ship structural design technology includes components related to nonlinear hydrodynamics, nonlinear dynamics, and a probabilistic or reliability-based analysis of ship hydrodynamic loading. The thrust of the research conducted here at the University of Michigan was on the prediction of local loads resulting from bottom impact and flare slamming. Details of spray jet development and flow separation points have been investigated and their influence on the overall hydrodynamic loads determined.

The project's goal has been the development of a fundamentally sound methodology by which the design hydrodynamic loads acting on a vessel in extreme seas can be computed. In this final phase of the project, emphasis was on the prediction of local loads resulting from bottom impact and flare slamming for symmetric and asymmetric hull shapes. The result of the analysis is time histories of pressures and local loads which can now be incorporated into subsequent ship structural analysis.

Significant Accomplishments

1. Two dimensional, asymmetric impact.

The two-dimensional or slender body impact model is derived using the method described by Xu, Troesch, and Vorus (1997). (This publication has been attached as an appendix.) The research efforts were directed towards an understanding of the physics of flow separation from the hull when time-dependent thin spray sheets are formed. This phenomenon occurs when the jet head reaches a knuckle or chine in the hull or more generally when the jet head reaches a location on the hull's surface where the surface curvature exceeds that which would normally occur in an unrestrained jet. When the jet head passes over a chine, that transition between the two flow regimes is referred to as the transition from "chines dry" to chines wet" flow.

For symmetric impact, the chines dry and chines wet flow of constant deadrise hulls has been developed for slender and two dimensional bodies and for a restricted class of three dimensional bodies. Under certain conditions, the chines dry flow may be self-similar. These theories also demonstrate the substantial drop in pressure when chines wet flow, which is completely non-similar, occurs. The asymmetric flow problem is more difficult in that there is no period in which the flow can be treated as a similarity flow. While asymmetric hulls have two separation points at the two chines, the side with the lower deadrise angle experiences chines wet flow sooner than the

side with the larger deadrise angle due to the higher jet velocities. A second type of flow may occur when one deadrise angle is significantly larger than the other and chines wet flow starts from the instant of impact.

The solution of the time dependent impact of asymmetric hulls requires a complete description of the initial conditions of the flow field at the instant of impact. Xu, Troesch, and Vorus (1997) have determined the combination of deadrise angles for which one could expect the flow types - separation at both chines or separation at the chine and keel.

2. Development of time-dependent impact hydrodynamics, including non-separated and separated flows, i.e. chines dry and chines wet, respectively.

The hydrodynamic forces were coupled with simple multiple-degree-of-freedom systems demonstrating the effect of combined hydrodynamic and elastic impact motions. Coupled wedge impact and elastic hull response has been analyzed. A simplified lumped-mass model for the hull structure was assumed. A time-dependent free surface impact boundary value problem was used to estimate the impact load acting on a rigid, constant deadrise section. The work has shown the significant difficulties associated with solving the fully nonlinear boundary value problem when time dependent spray sheets are present and assumptions based upon similarity flows are no longer valid. In addition, the impact problem for a finite beam body, where the hull surface and water surface separate, such as in chines wet flow, has been computed. The characteristics of the flow, which include the pressure distribution and jet head velocity, change dramatically as the jet edge passes over the chine. When the jet head reaches a location on the hull's surface where the surface curvature exceeds that which would normally occur in an unrestrained jet, such as at the chine, the pressure drops significantly. The model, which has been compared extensively with steady planing pressure, includes the essential characteristics of chines dry and chines wet impact.

The results of the impact studies were presented at the 21st Symposium on Naval Hydrodynamics, Norway, June, 1996 (Kim, Vorus, Troesch, and Gollwitzer). (This work was also supported under the previous ONR impact project, N00014-94-1-0652.)

The asymmetric impact theory developed by Xu, Troesch, and Vorus (1997) was used to solve the resulting motions of hulls impacting the water with an angle of heel. Both vertical water entry and rolling equations of motion were solved in the time domain. Numerical examples of a prismatic hull in free-fall impact were compared with drop test results. The experiments were conducted at the Coastal Systems Station, Panama City Florida. The results of the comparison, which are uniformly good, are to be presented at the 17th OMAE conference in July (Xu, Troesch and Peterson, 1998). (This publication has also been attached as an appendix.)

3. Collection of impact load field data.

Carolyn Frank, a University of Michigan Ph.D. student and an UM/National Defense Science and Engineering Graduate Fellowship scholar participated as a summer intern at CSS collecting impact data. This ONR project provided partial support for the subsequent data reduction and comparison with theory.

4. Technology Transfer.

This project has been part of a larger effort to predict impact loading and planing hull performance including occupant comfort and vessel steady state and dynamic responses. Participating organizations who are providing either direct financial support or in-kind match, include the University of Michigan, Coastal Systems Station (CSS), National Coastal Resources & Development Institute (NCRI Project, *Transfer of High -Speed Planing Graft Technology to the Private Sector*") and the Gulf Coast Region Maritime Technology Center at the University of New

Orleans (GCRMTC). The NCRI project has 12 industry participants who are evaluating the planing boat technology. An important objective of the project is to make available to the small craft industry, an advanced, workstation-based, design package that will include a number of inter-related programs. One part of the performance program includes theories on planing hull lift and drag; these theories are based upon the two dimensional impact models supported by this ONR project. Upon validation, the impact results will be incorporated into the planing dynamics analysis program.

The impact work also has direct application for shock mitigation, an area of concern with the ONR Naval Special Warfare (NSW) High Speed Planing Boat Shock Mitigation technology program. The Naval Coastal Systems Center at Panama City, Florida has expressed interest in the results of the work for 6.2 and 6.3 type applications. A. W. Troesch has been interacting with CSS/NSWC personnel Mr. R. Gollwitzer and Dr. R. Peterson on a regular basis analyzing impact drop test results and resulting structural accelerations.

LIST OF PUBLICATIONS

Kim, D. J., Vorus, W. S., Troesch, A.W., and Gollwitzer, R. M., "Coupled Hydrodynamic Impact and Elastic Response," Proceedings of the 21st Symposium on Naval Hydrodynamics, Norway, June, 1996. (Presented by AWT)

Troesch, A.W., "Recent Advances in the Analysis of High Speed Planing Hydrodynamics and Dynamics," Proceedings of the 16th Congress of Brazilian Naval Architects and Ocean Engineers, September, 1996. (Presented by AWT)

Wang, M.-L. and Troesch, A.W., "Numerical Stability Analysis for Free Surface Flows," ," International Journal for Numerical Methods in Fluids, Vol.24, 1997, pp.893-912.

Xu, L., Troesch, A.W., and Vorus, W. S., "Asymmetric Vessel Impact and Planing Hydrodynamics," submitted to Journal of Ship Research, October, 1997.

Xu, L., Troesch, A.W., and Peterson, R., "Asymmetric Hydrodynamic Impact and Dynamic Response of Vessels," submitted for publication in Proceedings, 17th International Conference on Offshore Mechanics and Arctic Engineering and Journal of Offshore Mechanics and Arctic Engineering, January 1998.

Xu, L., and Troesch, A.W., "The physics of high speed planing surfaces," in preparation for submission to Physics of Fluids, January 1998